Available online at www.sciencedirect.com
SCIENCE DIRECT®
Renewable and Sustainable Energy Reviews
11 (2007) 57–77
RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS
www.elsevier.com/locate/rser

Comparing wind and photovoltaic stand-alone power systems used for the electrification of remote consumers

J.K. Kaldellis[a,*], K.A. Kavadias[a], P.S. Koronakis[b]

[a] *Lab of Soft Energy Applications and Environmental Protection, Mechanical Engineering Department, TEI Piraeus, P. O. Box 41046, Athens 12201, Greece*

[b] *Fluid Mechanics Laboratory, Mechanical Engineering Department, TEI Piraeus, P.O. Box 41046, Athens 12201, Greece*

Received 20 November 2004; accepted 28 December 2004

Abstract

Wind power and photovoltaic driven stand-alone systems have turned into one of the most promising ways to handle the electrification requirements of numerous isolated consumers worldwide. In this context, the primary target of the present work is to estimate the appropriate dimensions of either a wind power or a photovoltaic stand-alone system that guarantees the energy autonomy of several typical remote consumers located in representative Greek territories. For all regions examined, long-term wind speed and solar radiation measurements as well as formal meteorological data are utilized. Accordingly, special emphasis is put on the detailed energy balance analysis of the proposed systems on an hourly basis, including also the battery bank depth of discharge time evolution. Finally, comparison is made between the wind and the solar based systems investigated, proving that in most Greek regions either a wind or photovoltaic driven stand-alone system is able to cover the electrification needs of remote consumers, at a moderate first installation cost, without any additional energy input.
© 2006 Elsevier Ltd. All rights reserved.

Keywords: Wind power stand-alone system; Photovoltaic stand-alone system; Energy balance; Battery capacity; System comparison

*Corresponding author. Tel.: +210 5381237; fax: +210 5381348.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).
URL: http://www.sealab.gr.

1364-0321/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2004.12.001

Contents

1. Introduction

Greece, being located in the SE European edge, possess excellent wind and abundant solar potential, since in several areas the wind speed exceeds the 10 m/s at 30 m height, while the annual solar energy approaches the 1900 kWh per square meter [1]. On the other hand, the country is strongly depended on imported oil and natural gas, which represent almost the 75% of the domestic energy consumption [2].

Besides, in Greece, due to its geographical distribution, exist several thousands of remote consumers [3,4], located on the numerous small and medium-sized islands scattered throughout the Aegean and Ionian Archipelagos, as well as in rural areas of mainland, i.e. country houses, shelters, telecommunication stations etc. All these isolated consumers have no direct access to reliable electrical networks, covering their electrification needs using small diesel-generator sets.

In this frame, the present study investigates the possibility of using either a wind power [3,5,6] or a photovoltaic [7–9] driven stand-alone system to meet the electricity demand of all these remote consumers. Thus, the primary target of the present study is to estimate the dimensions of either a wind power or a photovoltaic stand-alone system that guarantees the energy autonomy of a typical remote consumer. Accordingly, special emphasis is put on the detailed energy balance analysis of these systems on an hourly basis, including also the battery bank depth of discharge time evolution. Finally, comparison is made between the wind and the solar based systems for various representative wind and solar potential profiles, proving that in most Greek regions a wind or solar driven stand-alone system is able to cover the electrification needs of remote consumers at a moderate first installation cost.

2. Description of the wind/solar stand-alone system

The proposed by the authors [3,7] stand-alone system (Figs. 1 and 2) comprises either a small wind converter feeding -via a UPS of similar nominal power- the AC load of the system or a small photovoltaic generator of ‘z’ panels properly connected to meet via a charge controller and an inverter the consumption load demand. In case that the electricity demand is inferior to the corresponding wind turbine or photovoltaic generator production, the energy surplus is stored to a battery row via the battery charge controller. Finally, in cases that the wind or the solar energy production cannot fulfill the load

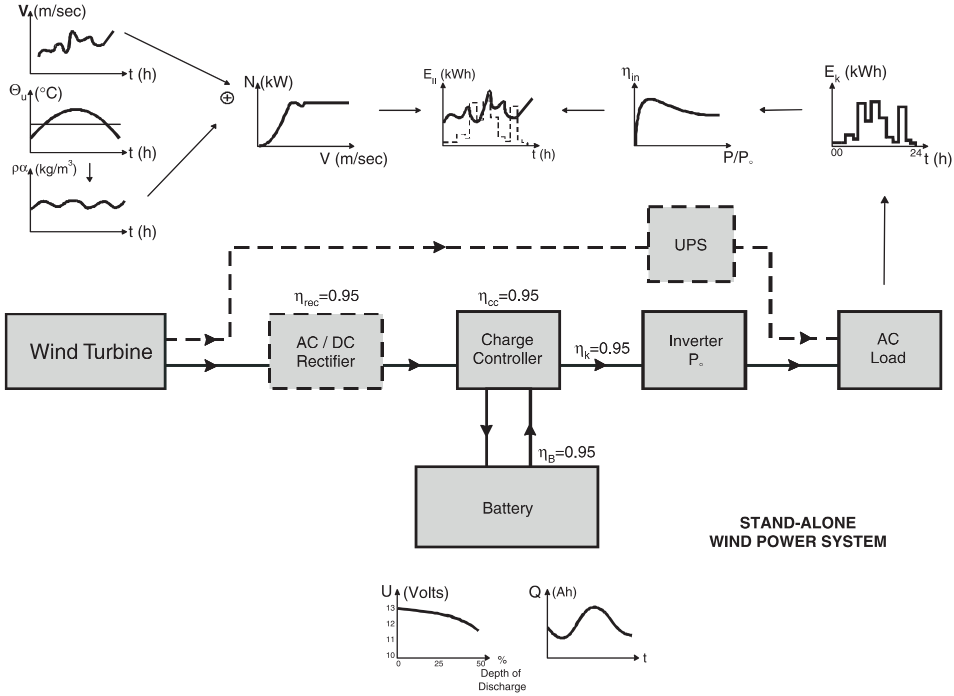


Fig. 1. Proposed stand-alone wind power system.

demand, a DC/AC inverter is used to transform the battery output in order to meet the system's power requirements. More precisely the proposed stand-alone systems are described as follows.

2.1. Wind power system

As shown in Fig. 1 the wind power system is based on:

i. A small wind converter of rated power 'N_o' kW (i.e. $N_o \leqslant 20$ kW) and specific power curve '$N_{WT} = N(V)$' for standard day conditions [3]
ii. A lead-acid battery with cell capacity of 'Q_{max}', maximum depth of discharge 'DOD_L' ensuring a long term operation and output voltage 'U_b'
iii. An AC/DC rectifier of 'N_o' kW and U_{AC}/U_{DC} operation voltage values
iv. A charge controller of 'N_o' kW, maximum 8 h charge rate 'R_{ch}' and outlet voltage 'U_{CC}'
v. A UPS of 'N_p' kW, frequency of 50 Hz, autonomy time '$\delta t = 2$ min' and operational voltage 220/380 V
vi. ADC/AC inverter of 'N_p' kW, frequency of 50 Hz and operational voltage 220/380 V [3]

The main system dimensions are the wind turbine rated power 'N_o' and battery size 'Q_{max}', while the inverter maximum power is directly related to the consumption peak load demand 'N_p', see also [10].

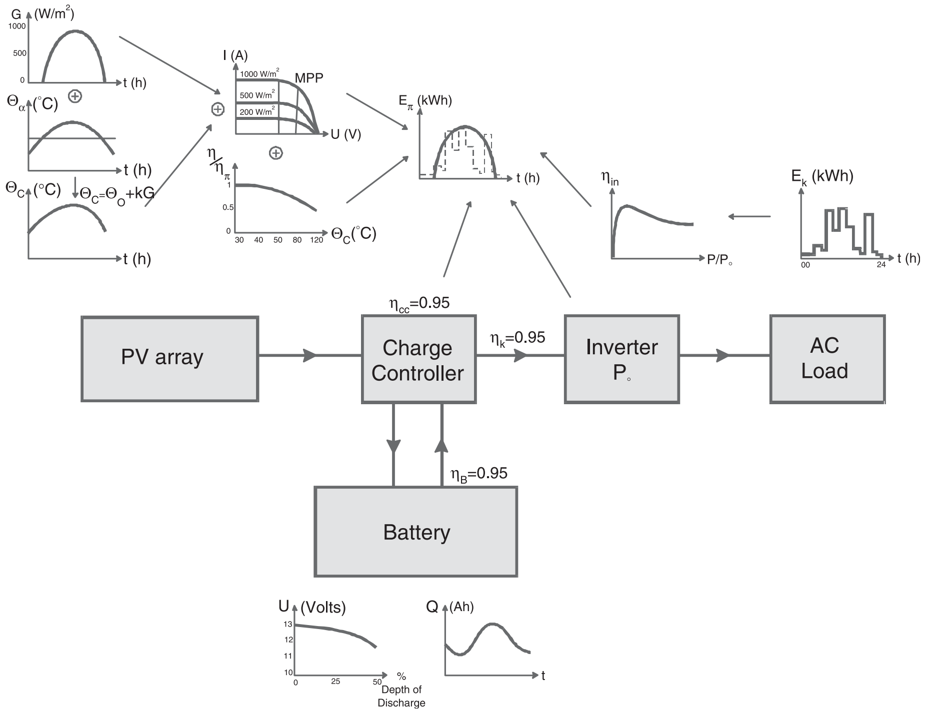


Fig. 2. Proposed photovoltaic stand-alone system for isolated consumers.

2.2. Photovoltaic power system

Accordingly, the proposed stand-alone photovoltaic system (Fig. 2) consists of:

i. A photovoltaic system of ‘z’ panels (‘N_+’ maximum power of every panel, $N_{PV} = z.N_+$) properly connected (z_1 in parallel and z_2 in series) to feed the charge controller to the voltage required [11]
ii. A lead acid battery storage system for ‘h_o’ hours of autonomy, or equivalently with total capacity of ‘Q_{max}’, operation voltage ‘U_b’ and maximum discharge capacity ‘Q_{min}’ (or equivalently maximum depth of discharge ‘DOD_L’)
iii. A DC/AC charge controller of ‘N_c’ rated power, maximum 8 h charge rate ‘R_{ch}’ and charging voltage ‘U_{CC}’
iv. A DC/AC inverter of maximum power ‘N_p’ able to meet the consumption peak load demand, frequency of 50 Hz and operational voltage 220/380 V

where ‘N_p’ is the maximum load demand of the consumption, including a future increase margin (e.g. 30%). Taking into account that the proposed system has an operational life of at least twenty years, it is assumed reasonable to take into consideration a five-year forecast of the expected electricity consumption. The two governing parameters of the proposed installation are the number ‘z’ and the rated power ‘N_+’ of each photovoltaic panel used along with the battery maximum necessary capacity ‘Q_{max}’.

Both stand-alone systems include also the non-active part of the installation, including supporting structures, power conditioning devices and wiring.

2.3. Stand-alone systems operational modes

During the long-lasting service period of the proposed stand-alone system (20–30 years is assumed to be realistic), the following operational modes may appear:

a. The power demand 'N_D' is less than the power output of renewable energy station 'N_{RES}' (where $N_{RES} = N_{WT}$ or $N_{RES} = N_{PV}$), i.e. ($N_{RES} > N_D$). In this case the energy surplus ($\Delta N = N_{RES} - N_D$) is stored via the rectifier (only for wind power systems producing AC) and the battery charge controller. If the battery is full ($Q = Q_{max}$), the residual energy is forwarded to low priority loads.
b. The power demand is greater than the renewable energy station power output ($N_{RES} < N_D$), which is not zero, i.e. $N_{RES} \neq 0$. In similar situations, the energy deficit ($\Delta N = N_D - N_{RES}$) is covered by the batteries via the battery charge controller and the DC/AC inverter.
c. There is no renewable energy production (e.g. low wind speed or zero solar radiation, system not available), i.e. $N_{RES} = 0$. In this case the entire energy demand is covered by the battery charge controller-DC/AC inverter subsystem, under the condition that $Q > Q_{min}$.

In cases (b) and (c), when the battery maximum depth of discharge is exceeded, an electricity management plan should be applied; otherwise the load would be rejected. In this context, a system-monitoring device may encourage operators to remarkably improve the efficiency operation of the autonomous wind/solar power station. Finally, for practical reasons, in an attempt to preserve the stand-alone system energy autonomy, an emergency energy consumption management plan is also necessary, in order to face unexpected energy production problems related to 'Force Majeure' events.

3. Computational algorithms presentation

As already mentioned, the primary prospect of this analysis is to estimate the appropriate dimensions of a stand-alone wind or solar power station for remote consumers sited all around Greece. The main inputs of the problem are:

- Detailed meteorological data, including either wind speed 'V' or solar radiation 'G' measurements for a given time period (e.g. one year minimum)
- Ambient temperature 'θ' and pressure 'p' data for the entire period analysed
- Operational characteristics of the wind turbine (i.e. specific power curve '$N_{WT} = N(V)$' for standard day conditions) or of the photovoltaic modules (current, voltage) selected, i.e. $I = I(U,G)$ and 'N_+'
- Operational characteristics of all the other electronic devices of the installation, i.e. inverter efficiency, AC/DC rectifier performance (only for wind driven systems), battery cell (Q–U;θ) curve etc.
- The electricity consumption profile, based on information provided by the Hellenic National Statistical Agency [3,7], on an hourly basis (see Fig. 3), being also dependent [12–14] upon the selected period of analysis (winter, summer, other).

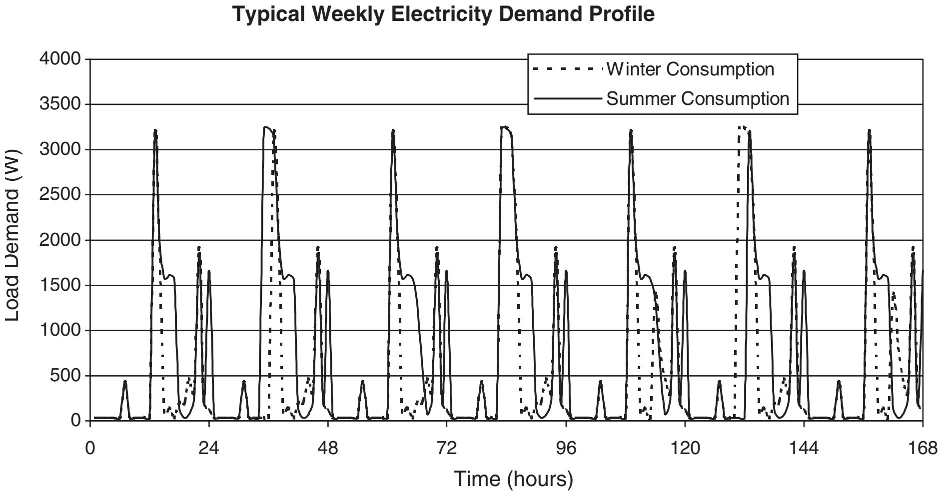


Fig. 3. Typical electricity demand profile of the remote consumer analyzed.

Accordingly, for the estimation of the appropriate configuration of a wind or solar stand-alone system able to guarantee the energy autonomy of an isolated consumer two fast and reliable numerical algorithms (i.e. WINDREMOTE-II and FOTOV-III, respectively) have been created [3,11], able to analyze in detail the energy behaviour of the above described installation for a selected time period. The main steps of the two algorithms (see also Figs. 4 and 5) are as follows:

a. For every region analysed, select a ($N_o - Q_{max}$) or ($z - Q_{max}$) pair, respectively.
b. For every time point of a given time period (with a specific time step) estimate the energy produced by the renewable energy station, i.e. 'N_{WT}' by the wind turbine or 'N_{PV}' by the photovoltaic generator, taking into account the existing meteorological parameters (i.e. wind speed or solar radiation, the ambient temperature and pressure) and the selected wind turbine or photovoltaic panel power curve.
c. Compare the renewable energy production 'N_{RES}' with the isolated consumer energy demand 'N_D'. If any energy surplus occurs ($N_{RES} > N_D$), this energy is stored to the battery bank and a new time point is examined (i.e. proceed to step b). Otherwise, proceed to step (d).
d. The energy deficit ($N_D - N_{RES}$) is covered by the energy storage system, if the battery is not near the lower limit ($Q > Q_{min}$). Accordingly proceed to step (b). In cases that the battery is practically empty ($Q \leqslant Q_{min}$), the load is rejected for an hour period and the complete analysis is repeated, starting from step (a), up to the case that the no-load rejection condition is fulfilled for the complete time period examined. If the desired energy autonomy is obtained define $Q^* = \min\{Q_{max}\}$.
e. Next, the wind turbine rated power or the number of photovoltaic panels is increased and the calculations are repeated. Thus, after the integration of the analysis a ($N_o - Q^*$) or a ($z - Q^*$) curve is predicted which guarantees the isolated consumer energy autonomy for the investigated period.

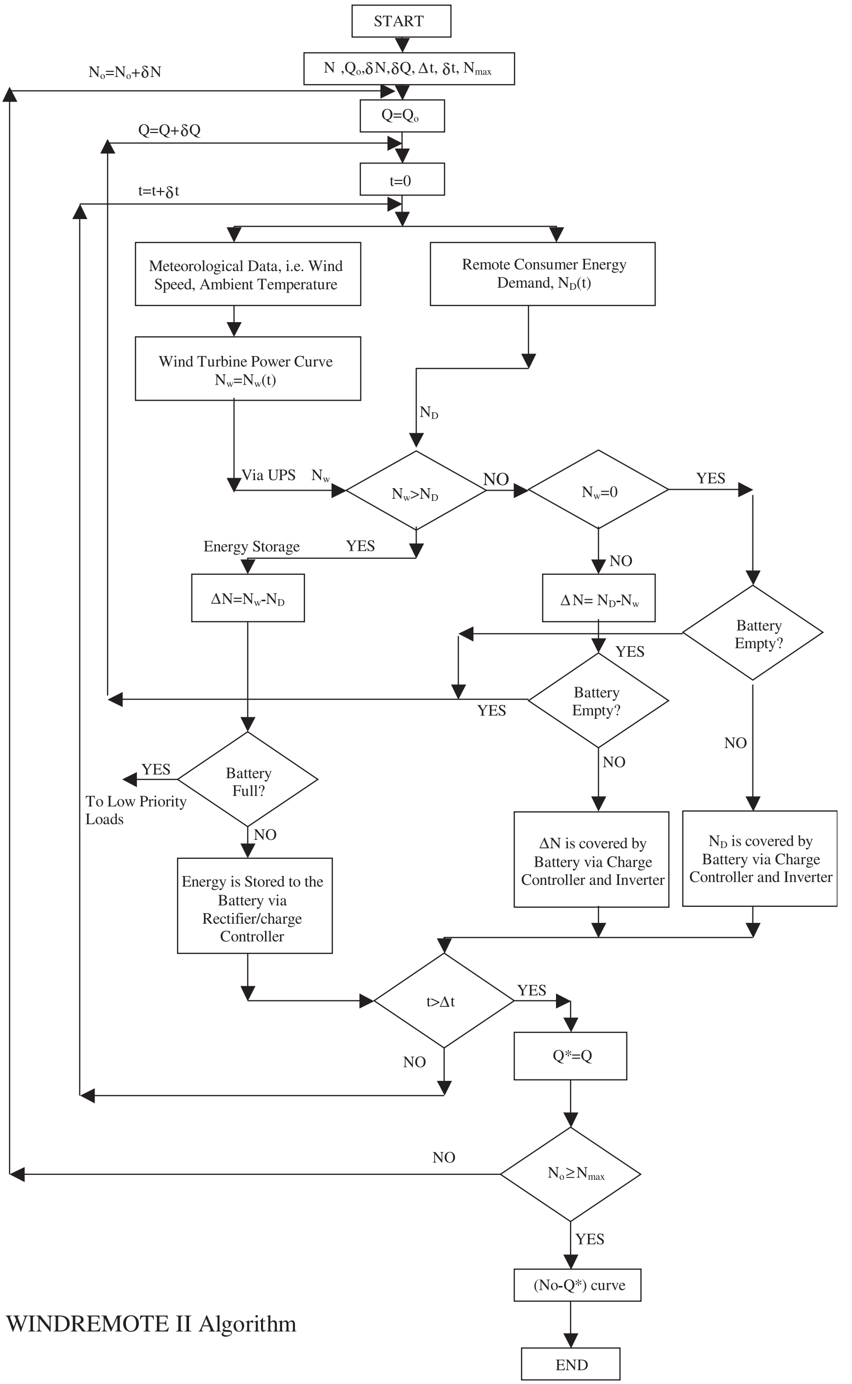


Fig. 4. WINDREMOTE-II Algorithm.

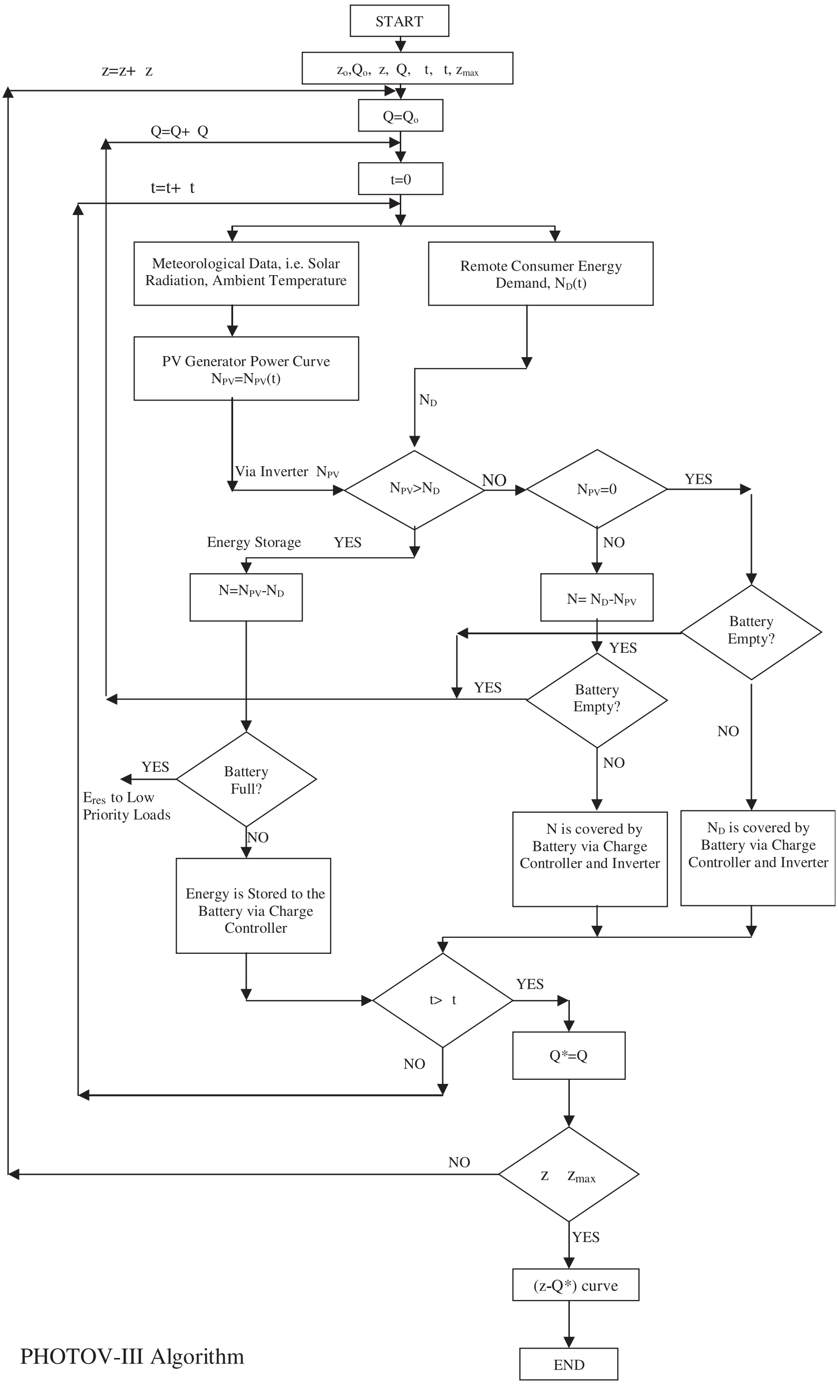
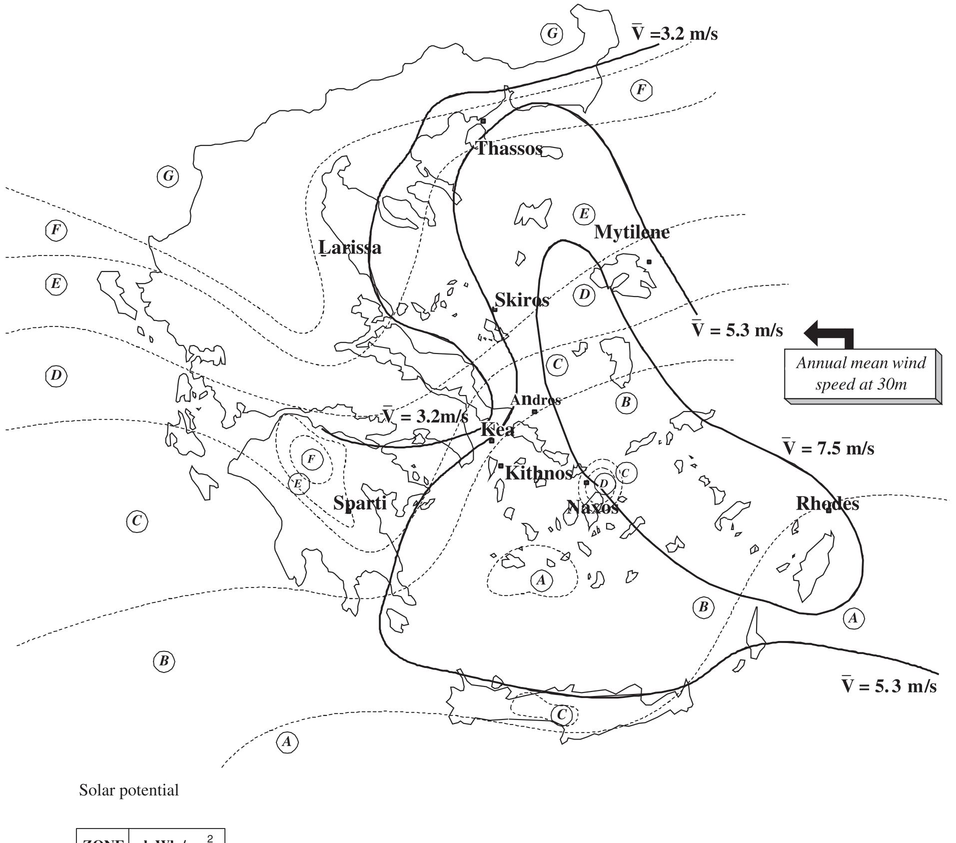


Fig. 5. PHOTOV-III Algorithm.

At this point it is important to mention that for every (N_o–Q^*) or (z–Q^*) pair ensuring the energy autonomy of the remote system, a detailed energy production and demand balance time-distribution is available along with the corresponding time-series of battery depth of discharge.

4. Application results

The present analysis should be applied for several typical Greek territories possessing representative wind and solar potential, see Fig. 6. For the regions selected long-term wind



Solar potential

ZONE	k Wh / m ^{2}
A	> 1650
B	1600 - 1649
C	1550 - 1599
D	1500 - 1549
E	1450 - 1499
F	1400 - 1449
G	< 1399

Fig. 6. Wind-solar potential in Greece.

Table 1
Annual wind potential characteristics of the areas analyzed

Island	Annual mean wind speed (m/s)	Max. calm spell duration (h)
Andros	9.56	41
Naxos	7.54	94
Skiros	7.01	112
Kithnos	6.58	178
Kea	6.09	210

speed and solar irradiance measurements [15] exist, as well as formal meteorological data. More specifically, for the installation of wind power stand-alone systems the cases analyzed (see Table 1) include:

- a very high wind potential area (Andros island, mean wind speed 9.5 m/s),
- a high wind potential area (Naxos island, mean wind speed 7.5 m/s),
- a medium-high wind potential area (Skiros island, mean wind speed 7.0 m/s),
- a medium wind potential area (Kithnos island, mean wind speed 6.5 m/s) and
- a medium-low wind potential area (Kea island, mean wind speed 5.8 m/s)

To get a clear-cut picture of the wind potential difference, Fig. 7 demonstrates the daily average wind speed time series for the best and the worst wind potential cases examined, for an entire year. There is a remarkable wind speed value difference for almost every day of the year between Andros and Kea islands. Hence, applying the WINDREMOTE-II algorithm to the above islands we get the results of Fig. 8. In this figure one may find the corresponding wind turbine rated power and battery bank capacity combinations that guarantee one-year energy autonomy without any external energy input. According to the results obtained, there is a significant battery capacity reduction as the wind turbine rated power increases. This increase is more abrupt for the high wind potential areas, while the medium wind potential areas present milder distribution. Besides, for all regions examined, the battery size tends to an asymptotic value as the wind turbine size surpasses a specific value, which is depending on the wind potential quality. Finally, it is important to note that for the relatively low wind potential areas the battery size is significantly bigger than for the medium or high wind potential case. In fact, Naxos and Andros islands tend to almost the same asymptotic battery capacity value, despite their remarkable wind potential difference, see also Table 1. On the contrary, the battery capacity difference between Kea and Kithnos islands is quite large, although for these two islands the annual mean wind speed difference is less than 1 m/s. Kithnos and Skiros islands distributions are rather similar, although Skiros island possesses a slightly higher annual mean wind speed.

Subsequently, for the installation of photovoltaic power stand-alone systems the cases analyzed (see Table 2) include:

- a high solar potential island of Aegean Sea (Rhodes island, annual solar energy 1843 kWh/(m^2.year) at horizontal plane),
- a S. Greece medium-high solar potential area (town of Sparti in Peloponnesus, annual solar energy 1731 kWh/(m^2.year)),

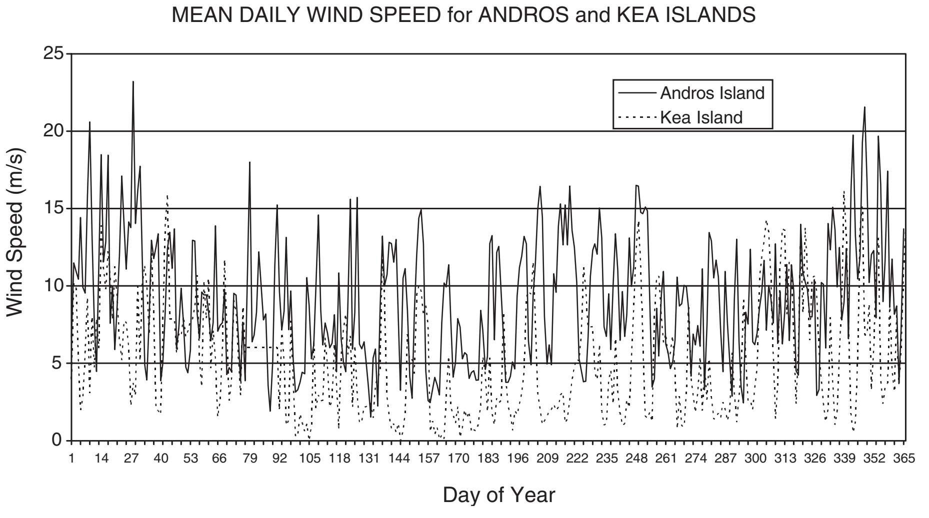


Fig. 7. Comparison of wind speed time series for the two extreme cases analyzed.

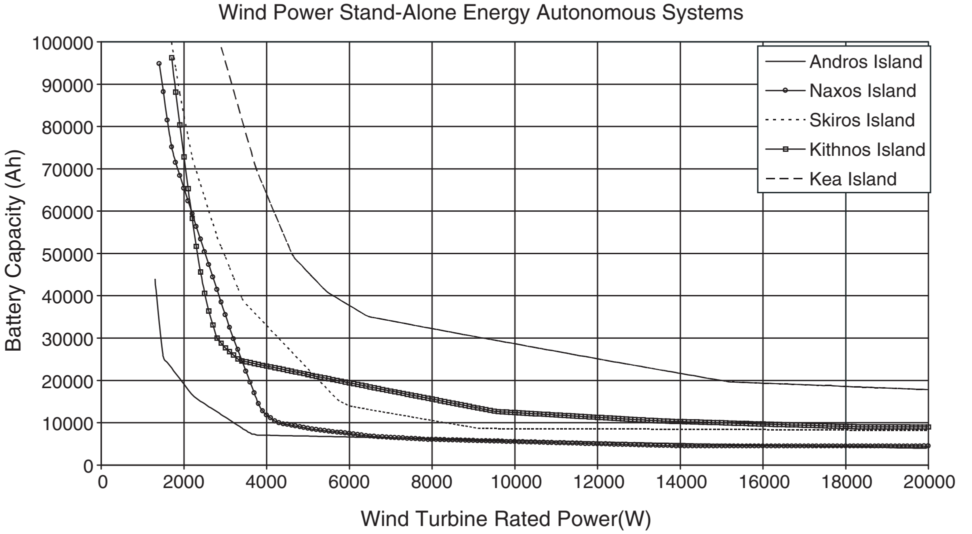


Fig. 8. Comparison of wind power stand-alone system configurations for selected Greek islands.

- a medium-high solar potential island of N.E. Aegean Sea (town of Mytilene in Lesvos island, annual solar energy 1680 kWh/(m^2.year)),
- a medium solar potential area of Central Greece (Larissa town, annual solar energy 1565 kWh/(m^2.year)) and
- a medium-low solar potential island of N. Aegean Sea (Thassos island, annual solar energy 1547 kWh/(m^2.year))

Table 2
Solar potential characteristics (at horizontal plane) of the areas analyzed

Region	Annual specific solar energy (kWh/(m^2.year))	Geographical latitude	Geographical longitude
Rhodes	1843	36°22′	28°13′
Sparti	1731	37°04′	22°26′
Mytilene	1680	39°06′	26°33′
Larissa	1565	39°38′	22°25′
Thassos	1547	40°56′	24°25′

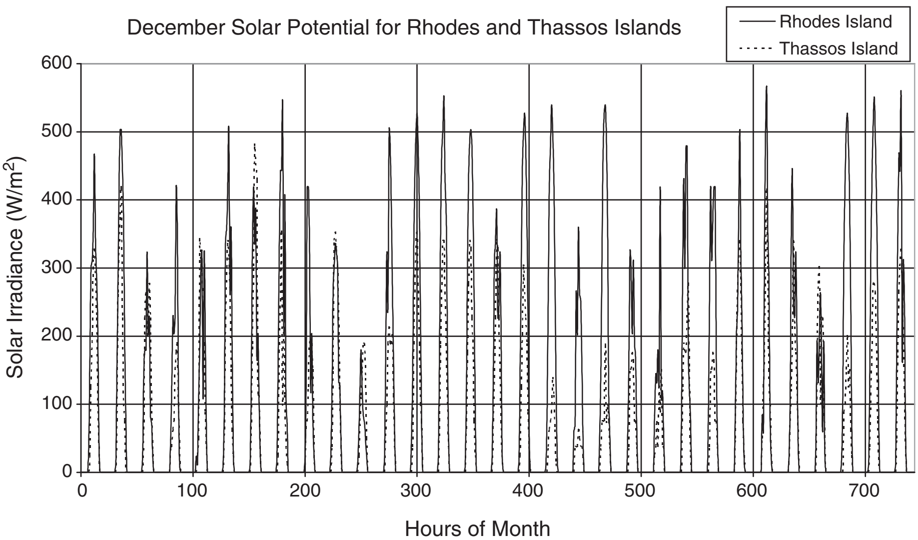


Fig. 9. Comparison of solar irradiance for the two extreme cases investigated.

Using the available experimental data (e.g. Fig. 9 for the worst solar potential month) and applying the PHOTOV-III numerical algorithm, the calculation results concerning the autonomous photovoltaic panel and battery capacity combination for the examined areas are summarized in Fig. 10. All the calculations are carried out using panel tilt angles equal to 60° [7,16]. For almost all energy autonomy curves, two distinct parts can be defined. In the first part of these curves the battery capacity is significantly reduced as the photovoltaic panels' number is slightly increased. This rapid change is more evident for high solar potential areas. In the second part, the battery capacity remains almost constant, not depending on the photovoltaic panels' number, achieving an asymptotic value depending mostly upon the local solar potential. It is also interesting to mention that the battery capacity of the stand-alone systems decreases remarkably as the available solar potential is improved. In any case, the differences encountered between the best and the worst solar potential cases are quite smaller than the ones of Fig. 8.

In an attempt to directly compare the wind and solar stand-alone power system configurations we present together in Fig. 11 three representative configurations of each

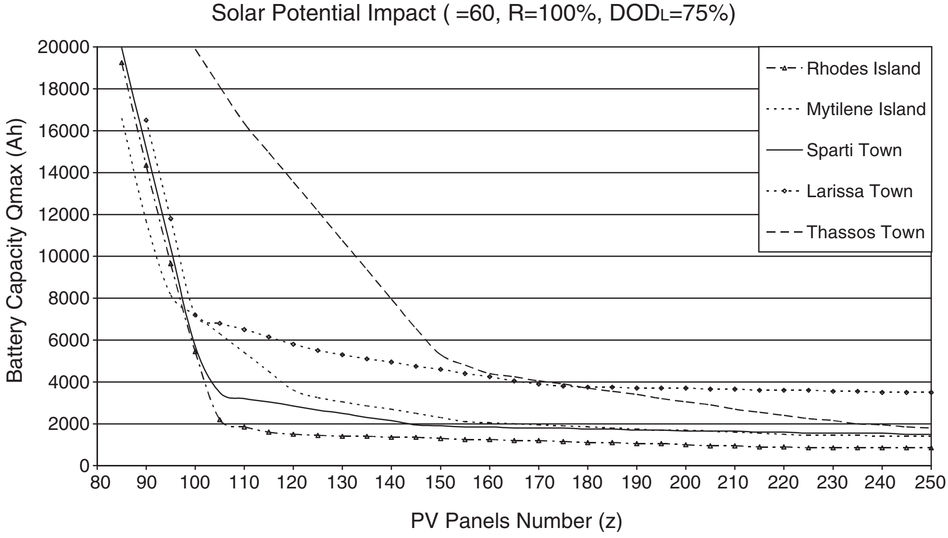


Fig. 10. Comparison of photovoltaic stand-alone systems configuration, for selected greek regions.

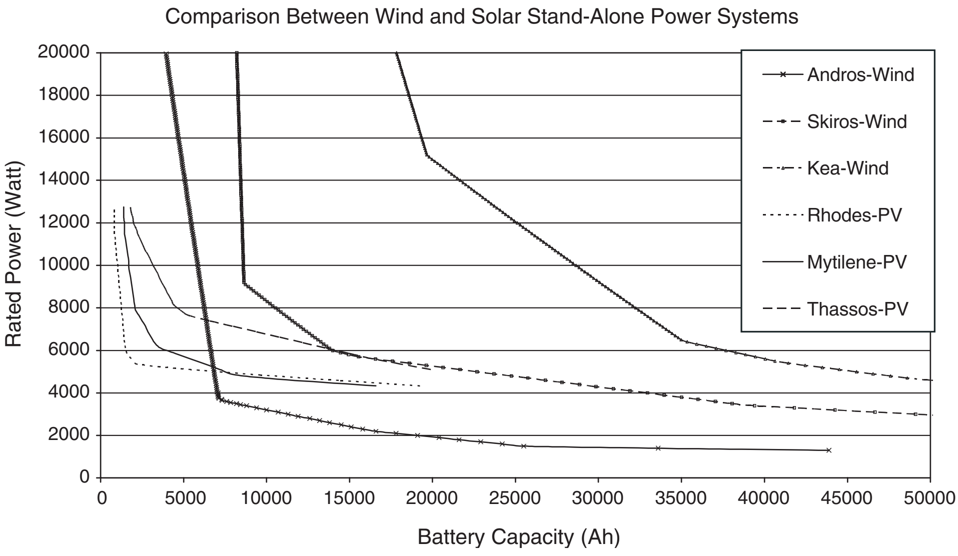


Fig. 11. Size comparison between wind and solar driven stand-alone systems located in Greece.

category that guarantee, on an annual basis, energy autonomy to the isolated consumer of Fig. 3. After a careful inspection of Fig. 11 data, covering the vast majority of Greek territory, one may state the following:

- The best wind potential areas need quite smaller stand-alone system configuration than the best solar potential case.

- On the other hand, medium-low wind potential areas need extremely huge configurations to guarantee energy autonomy.
- The necessary battery capacity of photovoltaic stand-alone systems is quite smaller than the minimum battery size required by wind-driven stand-alone systems. This may be explained by the fact that considerable calm spell periods may appear (Table 1) even in the best wind potential areas (stochastic behaviour of wind), while there is almost no possibility for a place in Greece, for two successive days, not to experience a fair solar energy gain; see for example Figs. 7 and 9.
- On the contrary the rated power of the wind turbines used are lower than the corresponding photovoltaic generator peak power, especially for medium-high wind potential cases. This fact can be attributed to the different available wind-solar energy density (i.e. kWh/m^2), as well as by the rather high efficiency discrepancy between the contemporary wind turbines (up to 45%) and the commercial photovoltaic panels ($\approx$13%) [17,18].

As a general conclusion one may state that -taking into consideration the ex-works cost difference between wind turbines and solar panels of the same rated power- wind based stand-alone systems present a relative size-advantage for high or medium-high wind potential cases. On the other hand, photovoltaic based stand-alone installations are using quite smaller batteries and need less maintenance for almost every area in Greece. Of course, a detailed cost-benefit analysis is necessary on long-term basis in order to reach final conclusions, under the current socio-economic environment.

5. Energy balance analysis of wind/solar stand-alone systems

As already mentioned, one of the main targets of the present study is to analyze and compare the energy behaviour of wind and solar based stand-alone systems located throughout Greece. In order to select a representative stand-alone configuration among the pairs of Figs. 8 and 10, the minimum initial cost combination is selected -using the analysis presented in [11,19] by the authors, for every region examined. Thus, the resulting outcomes are based on wind power and photovoltaic stand-alone systems that guarantee the remote consumers energy autonomy under the minimum first installation cost restriction.

To get an integrated picture of the proposed system energy balance, Fig. 12 demonstrates the annual energy balance of several wind power and photovoltaic standalone systems. Taking into consideration that energy demand is the same for every standalone system, it is interesting to note that the energy production of wind power systems is three to six times higher than the demanded energy, while the corresponding energy production of the photovoltaic installations is not greater than 1.5 the remote consumer energy demand. As a result, all wind power systems present quite higher losses than the photovoltaic ones, while their corresponding energy surplus is very high, exceeding the 150% of the energy consumption. This is not the case for the photovoltaic systems, since even in Thassos island case presenting the lowest solar potential, the energy rejection is slightly over 30% of the energy consumption.

Another interesting point related to the monthly energy analysis of the stand-alone systems investigated (Figs. 13 and 16) is the big differences between Andros and Kea islands energy distribution, where the Kea wind turbine is almost 15 kW, while the

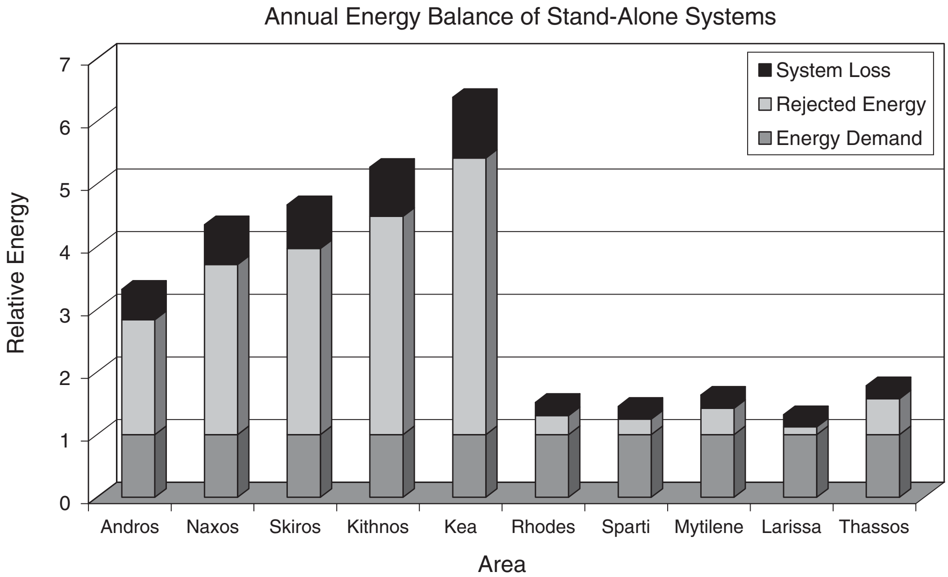


Fig. 12. Annual energy balance of wind and solar stand-alone systems.

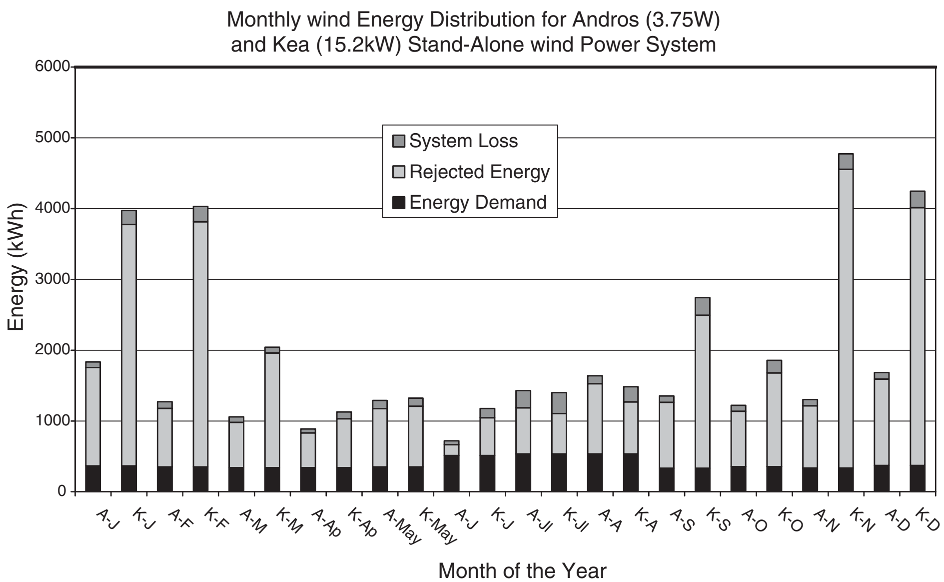


Fig. 13. Monthly energy balance of selected wind power stand-alone systems.

corresponding engine for Andros island is less than 4 kW. Despite this considerable size difference, during low wind speed periods (e.g. May to July) the wind energy production of these power stations is similar, due to the quite different wind potential of the areas.

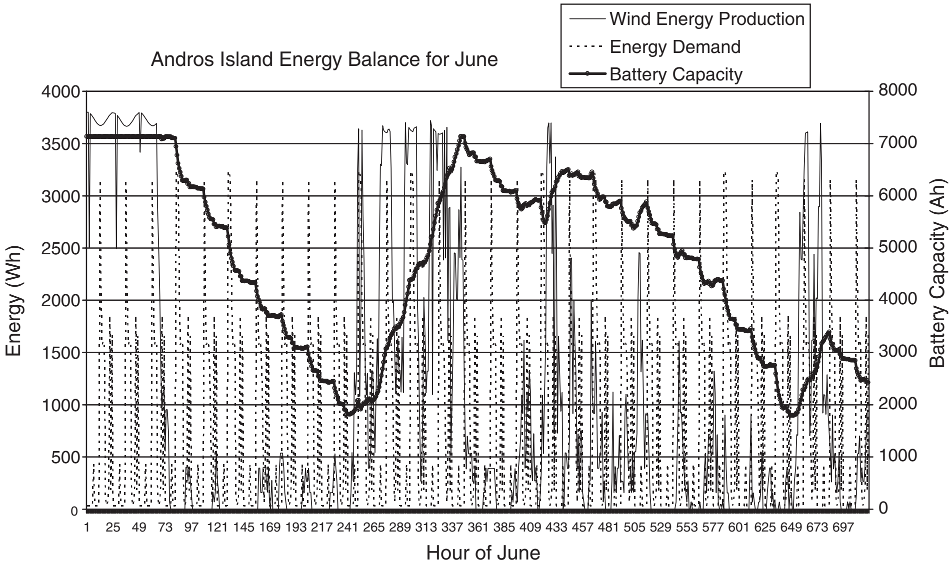


Fig. 14. Energy-battery capacity distributions of a wind power stand-alone system located in andros island.

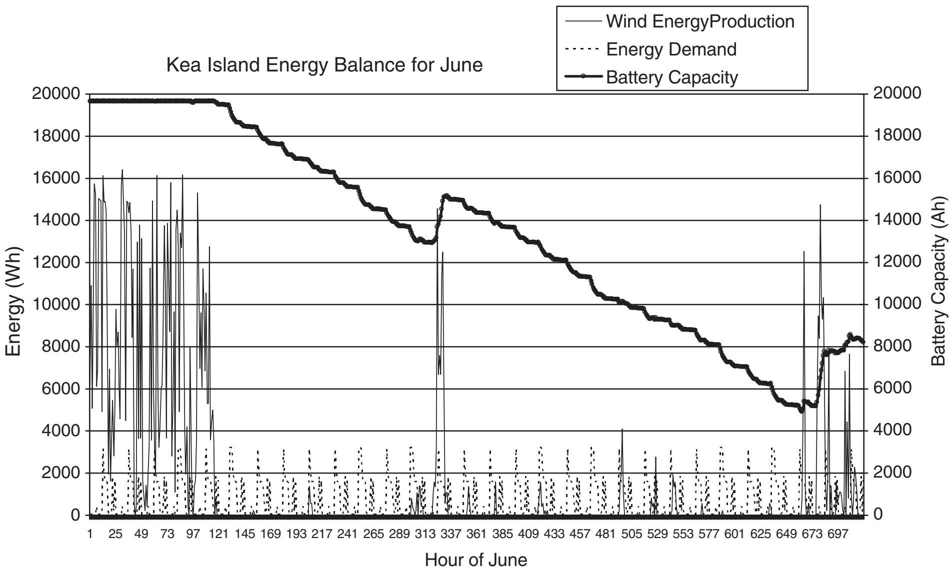


Fig. 15. Energy-battery capacity distributions of a wind power stand-alone system located in kea island.

In fact, comparing the detailed energy balance profile of these two islands during June (Figs. 14 and 15) one may state the following:

- The wind energy production in Andros (4 kW) is bigger than the one of Kea (15 kW)
- The calm spell periods of Kea island is much longer than Andros island

- In both cases there are two relatively long low wind speed periods leading to considerable battery energy storage decrease.
- Due to quite higher battery bank size, the first minimum battery discharging limit of Kea island is not very low, while in Andros island both minima are very near to the maximum battery DOD limit.
- Due to the relative smaller wind turbine used, the instantaneous wind energy production in Andros island is comparable with the energy demand, which is not the case for Kea island.
- Unfortunately, the excessive wind power of Kea stand-alone system during the first week of June is practically lost, since the system batteries are completely full.

Similarly, one may analyze the monthly energy profile of the photovoltaic standalone systems situated in the two extreme Greek solar potential regions, i.e. Rhodes and Thassos islands, keeping in mind that the Thassos stand alone system uses 50% more solar panels than the corresponding Rhodes one. As mentioned in Fig. 12, the photovoltaic energy production is primarily used to meet the energy consumption, while only a small portion of the energy production is finally rejected. This energy rejection takes place primarily during the hot months of the year and is more obvious for Thassos system. More specifically, the most difficult energy balance situation for this N. Aegean island is during December and January, where the photovoltaic generator hardly covers the installation load. On the contrary, for S. Greece installation the limited energy balance takes place during June and July, where the selected photovoltaic generator faces quite higher power demand, see also Fig. 3. In any case, the energy disposal by the photovoltaic generator is quite better than the one produced by wind turbines, a fact that may support the idea that photovoltaic panels are more convenient than micro wind converters, disregarding the first installation cost matter (Fig. 16).

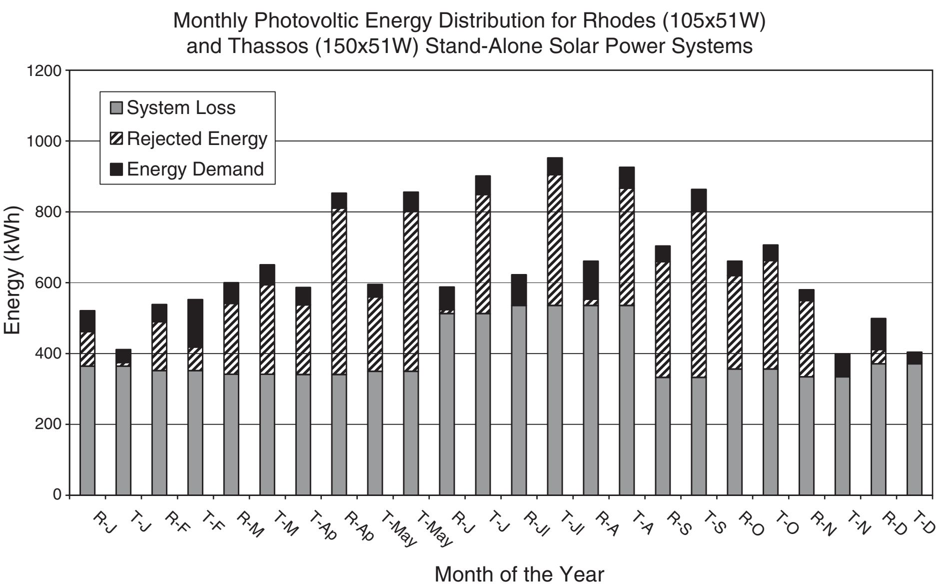


Fig. 16. Monthly energy balance of selected photovoltaic stand-alone systems.

Finally, in Figs. 17 and 18 one may find the energy balance time evolution along with the corresponding battery energy content for the two most difficult months of Rhodes and Thassos photovoltaic stand-alone systems, i.e. June and December respectively. On the basis of these two figures one may conclude that:

- Energy production in Rhodes island is comparable with the increased energy consumption of the installation, hence the problem is not due to the low solar irradiance in June but mainly due to the small system battery bank (only 2200 Ah). In fact, this means that the selected photovoltaic stand-alone system is almost perfectly adapted to the local conditions.
- On the other hand, there is a remarkable low energy production period during the 3rd week of December for Thassos island, which endangers the energy autonomy of the proposed stand-alone system.
- Even during this low solar potential period (December) the Thassos stand-alone system produces relatively high energy.
- The energy production of Rhodes island during June is almost constant, excluding a few cloudy days during the first week of the month.

Therefore, according to the information presented, both wind and solar based standalone systems can face the energy demand of the isolated consumer. To be more precise, the photovoltaic systems seem to be more adaptable to the specific energy consumption profile, although high wind potential areas may use smaller and less expensive configurations than the corresponding photovoltaic ones. On the other hand, wind driven stand-alone systems may be more attractive when supporting supplementary

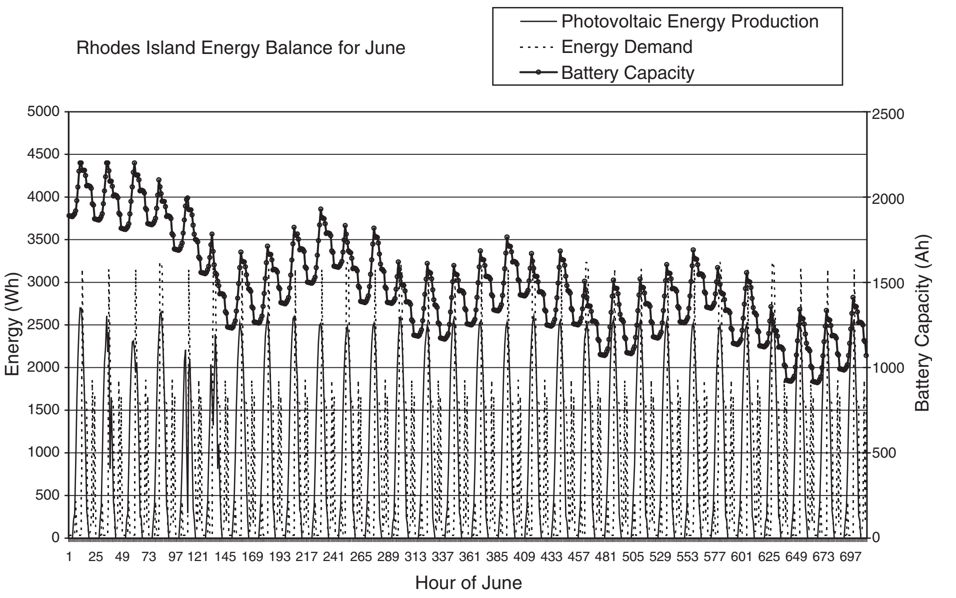


Fig. 17. Energy-battery capacity distributions of a photovoltaic stand-alone system located in rhodes island.

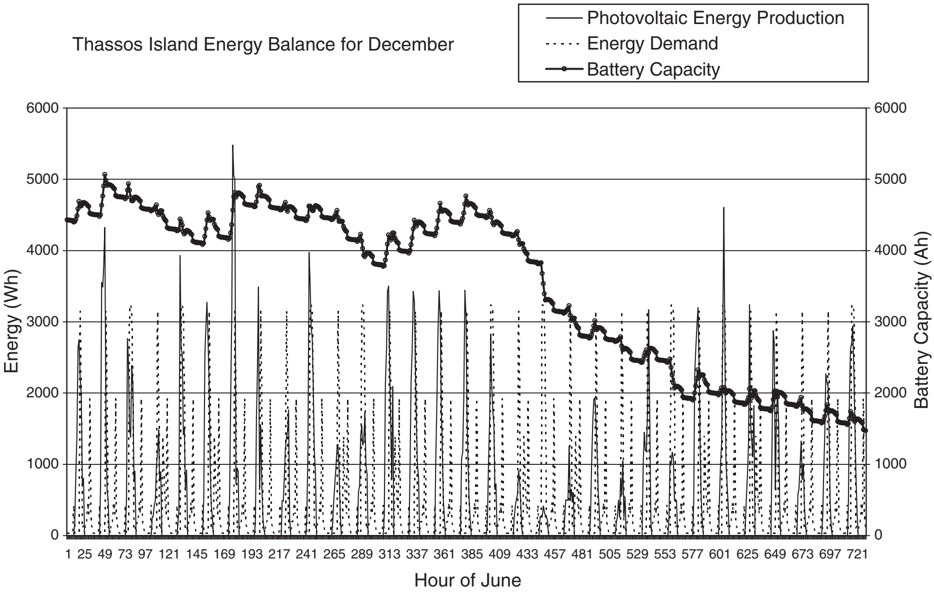


Fig. 18. Energy-battery capacity distributions of a photovoltaic stand-alone system located in thassos island.

second priority electrical loads, like small desalination plants [20], water pumps for irrigation purposes [21], small ice-making machines etc.

6. Conclusions

The possibility of using either a wind power or a photovoltaic driven stand-alone system to meet the electricity demand of typical remote consumers located in different places in Greece is investigated. For this purpose two independent stand-alone configurations are used, based respectively on a small wind converter or a small photovoltaic generator.

Applying the proposed methodology, one has the opportunity to estimate the two systems dimensions that guarantee energy autonomy of the installation for the entire period analyzed. For all regions examined, long-term wind speed and solar irradiance measurements, as well as other meteorological data are needed.

According to the results presented both wind or photovoltaic driven systems have the ability to cover the corresponding load demand. More specifically, for most regions analyzed the rated power of the wind turbine used is lower than the corresponding photovoltaic generator peak power. On the other hand the necessary battery capacity of the photovoltaic based systems is quite smaller than the one of the wind based installation. A long-term cost-benefit evaluation may be used, for each region separately, in order to reach to final estimates and conclusions.

Finally, a detailed energy analysis for both wind and solar driven stand-alone systems is presented, including also the system battery depth of discharge time-evolution. Generally speaking, the energy production of the wind power stand-alone systems is much higher than the corresponding power demand, while photovoltaic installations seem to be more adaptable to the power demand profile of the specific consumer. In this context, wind

driven systems may be more appropriate to cover additional second-priority loads, especially during high wind speed periods.

Summarizing, on the basis of the above presented information, one may definitely state that both stand-alone configurations can significantly contribute to the energy requirements of numerous isolated consumers all around Greece. More precisely, in regions of high or medium-high wind potential wind driven systems are definitely the best solution, including preliminary cost aspects. On the other hand, in most other situations photovoltaic driven installations use quite smaller batteries and may present even a remarkable initial cost advantage.

In any case, every one of the proposed configurations is able to guarantee the remote consumer energy autonomy without any additional energy input, while protecting the corresponding system batteries from deep discharge. For all these regions, wind or photovoltaic based stand-alone systems are possibly the best alternatives to meet the electrification requirements of isolated communities, improving also their life quality.

References

[1] Kaldellis JK, Vlachos G Th, Kavadias KA. Optimum sizing basic principles of a combined photovoltaic-wind-diesel hybrid system for isolated consumers. Proceeding of EuroSun 2002 International Conference, Paper W141, Bologna, Italy 2002.

[2] Greek Regulatory Authority of Energy, 2004, http://www.rae.gr.

[3] Kaldellis JK. Optimum autonomous wind power system sizing for remote consumers, using long-term wind speed data. J Appl Energy 2002;71(2):215–33.

[4] Jensen Th L. Renewable energy on small islands, 2nd ed, Forum for Energy and Development (FED) 2000.

[5] U.S. Department of Energy (DOE) 1997, Small wind energy systems for the homeowner, prepared by NREL, DOE/GO-10097-374, FS 135, USA.

[6] Notton G, Muselli M, Poggi P, Louche A. Stand alone wind energy systems sizing procedure with cost optimization, presented at 1999 European Wind Energy Conference and Exhibition, Nice, France 1999, p. 919–22.

[7] Kaldellis JK, Koronakis P, Kavadias K. Energy balance analysis of a stand alone photovoltaic system, including variable system reliability impact. Renew Energy J 2003;29(7):1161–80.

[8] Sidrach-de-Cardona M, Mora Lopez Li. A simple model for sizing stand alone photovoltaic systems. Solar Energy Mater Solar Cells J 1998;55(3):119–214.

[9] Arab AH, Driss BA, Amimeur R, Lorenzo E. Photovoltaic systems sizing for algeria. Solar Energy J 1995;54(2):99–104.

[10] Kaldellis JK, Tsesmelis M. Integrated energy balance analysis of a stand-alone wind power system, for various typical Aegean sea regions. Wind Energy J 2002;5(1):1–17.

[11] Kaldellis JK. Optimum techno-economic energy-autonomous photovoltaic solution for remote consumers throughout Greece. J Energy Convers Manag 2003;45(17):2745–60.

[12] Muselli M, Notton G, Louche A. Design of hybrid-photovoltaic power generator, with optimization of energy management. Solar Energy J 1999;65(3):143–57.

[13] Beyer HG, Degner T, Gabler H. Operational behaviour of wind diesel systems incorporating short-term storage: an analysis via simulation calculations. Solar Energy 1995;54(6):429–39.

[14] Lazou A, Papatsoris A. The economics of photovoltaic stand-alone residential households: a case study for various European and Mediterranean locations. Solar Energy Mater Solar Cells J 2000;62(4):411–27.

[15] Public Power Corporation. Wind speed and solar radiation measurements for Greece, 1980–85. Edition PPC, Athens, 1985.

[16] Bari S. Optimum slope angle and orientation of solar collectors for different periods of possible utilization. J Energy Convers Manag 2000;41:855–60.

[17] Masini A, Frankl P. Forecasting the diffusion of photovoltaic systems in southern Europe. A learning curve approach. Technol Forecast Social Change J 2002;70(1):39–65.

[18] Ackermann T, Soder L. An overview of wind energy-status 2002. Renew Sustain Energy Rev 2002;6(2002): 67–128.

[19] Kaldellis JK. Minimum stand-alone wind power system cost solution for typical Aegean sea islands. Wind Eng J 2002;26(4):241–55.

[20] Kaldellis JK, Kavadias KA, Kondili E. Renewable energy desalination plants for the greek islands, technical and economic considerations. Desalination J 2004;170(2):187–203.

[21] Kavadias K, Komnimoglou A, Kaldellis JK. Wind energy surplus management for remote consumers using a water pumping storage system. European Wind Energy Conference, Conference Proceedings, Bella Centre, Copenhagen 2001, p. 972–75.